Parton rescattering effect on particle production in ultra-relativistic p+p collisions

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The parton rescattering effect on the charged particle production in ultra-relativistic p+p collisions is studied by the parton and hadron cascade model, PACIAE, based on PYTHIA. We have calculated charged particle pseudorapidity density ($dN_{ch}/d\eta$) at mid-rapidity and the pseudorapidity distribution in inelastic and non-single diffractive p+p collisions at $\sqrt{s}$=200, 900, 5500, and 14000 GeV with the PYTHIA and PACIAE models. The calculated results of $\sqrt{s}$=900 GeV are well compared with the ALICE data. The calculated $dN_{ch}/d\eta$ as a function of center-of-mass energy well meets with the experimental data as well. Comparing the PYTHIA results (without parton rescattering) with the PACIAE results (with parton rescattering), it turned out that the parton rescattering effect plays an important role and this effect increases with increasing center-of-mass energy.

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I. INTRODUCTION

The jets, as remnants of hard-scattered quarks and gluons, have been investigated to explore the properties of partons [1]. Studying the hot QCD matter via jet quenching (partons lose energy on their way through the QCD medium) has now become an important role of jets and has been realized at RHIC [2, 3]. Experimentally extracting the partonic observables from final state hadrons with reconstruction method is now highly interesting [4, 5].

Another way to study the properties of partons is introduced recently. The p_T distribution of effective u (d) and s quarks are extracted from the ratio of $\Xi(p_T/3)/\phi(p_T/2)$ and $\Omega(p_T/3)/\phi(p_T/2)$ in the Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV , respectively [6, 7]. In this extraction it is assumed that the hadron's p_T is composed of its effective constituent quark's p_T/n (n is the number of effective constituent quarks in the hadron) and the different quark and anti-quark have the same p_T distribution.

The measurement of elliptic flow parameter v_2 relies on the analysis techniques which require high event multiplicity. Therefore, no report about the v_2 measurement in p+p collisions is published by now because of low multiplicity. However, in recent papers [8, 9, 10] it is argued that the elliptic flow parameter in high multiplicity p+p collisions at the LHC energy ($\sqrt{s}$=14000 GeV) may be measurable. Similarly, one could expect the formation probability of quark-gluon mater (QGM) in the p+p collisions at RHIC energy ($\sqrt{s}$=200 GeV) is very low [11]. The parton rescattering effect on the final state hadrons in p+p collisions at RHIC energy is weak as well [12]. However, those probability and effect may be visible in the p+p collisions at LHC or higher energy [12].

The study of ultra-relativistic p+p collisions is a door sill toward the nucleus-nucleus collisions at the same energy. Because the nucleus-nucleus collision can be decomposed into nucleon-nucleon collisions and the nucleon-nucleon collision can be well described by the perturbative QCD (pQCD) due to its relatively clear and simple physics. The results of p+p collisions are a worthy reference for nucleus-nucleus collisions. Thus the ALICE first successful measurements for p+p collisions at $\sqrt{s}$=900 GeV [13] not only demonstrate "the LHC and its experiments have finally entered the phase of physics exploitation" but also light the way studying Pb+Pb collisions at LHC energies. It also means the copious measurements in p+p collisions at LHC energies are forthcoming and will supply opportunities for the investigations of the issues mentioned above.

As a dedication to the ALICE first measurements, in this paper the parton and hadron cascade model PACIAE, based on PYTHIA, is used to analyze the ALICE first measurements, especially to explore the parton rescattering effect on the final state hadron in the ultra-relativistic p+p collisions. This investigation is not only a quick response to the ALICE first measurements but also a well preparation for the further studies in p+p and Pb+Pb collisions at LHC energies.

II. MODELS

The parton and hadron cascade model, PACIAE [14], is based on PYTHIA [15]. PYTHIA is a model for high energy hadron-hadron (hh) collisions. In the PYTHIA model a hh collision is decomposed into the parton-parton collisions. A hard parton-parton collision is described by the lowest leading order perturbative QCD (LO-pQCD) parton-parton interactions modified by the parton distribution function in a hadron. The soft

parton-parton collision is considered empirically. Because the initial- and final-state QCD radiations are considered in parton-parton interactions, the consequence of a hh collision is a partonic multijet configuration composed of di-quarks (anti-diquarks), quarks (anti-quarks), and gluons. This is followed by the string construction and the string fragmentation. So one obtains a final hadronic state for a hh (p+p) collision.

The differences between the PACIAE model and PYTHIA model, for p+p collision, are as follows:

- The string fragmentation mentioned above is switch-off temporarily in the PACIAE model. Therefore, if the di-quarks (anti-diquarks) are broken randomly into quarks (anti-quarks) the consequence of a hh (p+p) collision is a configuration of quarks, anti-quarks, and gluons. As such the partonic initialization stage for a p+p collision is realized.

- Then the rescattering among partons is introduced and performed by the Monte Carlo method until partonic freeze-out (no more parton-parton interaction at all). In this parton rescattering stage the LO-pQCD parton-parton interaction cross sections ($2 \rightarrow 2$) are employed [16].

- In the next hadronization stage, the partonic mat-

ter formed after parton rescattering is hadronized by the Lund string fragmentation regime [15] and/or coalescence model [14].

- The consequent hadronic matter suffers hadronic rescattering. We deal with hadronic rescattering as usual two-body collision [17], until hadronic freeze-out (hh collision pair is exhausted). This is the hadronic rescattering stage.

III. PARTON RESCATTERING EFFECT ON PARTICLE PRODUCTION

As we aim at the physics behind the experimental data rather than reproducing the data, in all calculations the model parameters are fixed at their default values, except the k factor, considering the higher order and unperturbative QCD corrections, is assumed to be equal to 3. Both inelastic (INEL) p+p and non-single diffractive (NSD) p+p collisions are calculated with and without parton rescattering at $\sqrt{s}$=200, 900, 5500, and 14000 GeV. The calculated results without parton rescattering will be indicated as PYTHIA and the results with parton rescattering as PACIAE. In addition, a similar calculations are also performed for the p+$\bar{\text{p}}$ collisions at $\sqrt{s}$= 900 GeV.

TABLE I: Charged particle pseudorapidity density at mid-rapidity ($|\eta| < 0.5$) calculated by the PYTHIA and PACIAE models for p+p collisions at various center-of-mass energies. The ALICE p+p and UA5 p+$\bar{\text{p}}$ data [13, 18] at $\sqrt{s}$=900 GeV are given as well. In the ALICE data the first error is statistical error and the second is systematic one.

| | p+p | | | | p+$\bar{\text{p}}$ | | |
	ALICE	320 tune[1]	PYTHIA	PACIAE	UA5	PYTHIA	PACIAE
INEL	$3.10 \pm 0.13 \pm 0.22$	2.46	2.59	2.80	3.09 ± 0.05	2.70	2.94
NSD	$3.51 \pm 0.15 \pm 0.25$	3.02	3.15	3.33	3.43 ± 0.05	3.30	3.50

[1] The PYTHIA results of the Perugia (320) tune taken from [21].

Table I gives the calculated charged particle pseudorapidity density at mid-rapidity ($|\eta| <0.5$), $dN_{ch}/d\eta$, together with the ALICE data [13] and UA5 data [18]. One sees in this table that:

- The PYTHIA results of $dN_{ch}/d\eta$ in this paper are within the range of three PYTHIA tunes [13]: from 2.33 [19] to 2.99 [20] for INEL and from 2.83 [19] to 3.68 [20] for NSD. Our PYTHIA results are close to the Perugia (320) tune [21].

- Both the ALICE and UA5 data are better reproduced by PACIAE than PYTHIA. This means the parton rescattering effect is important in reproduc-

ing the experimental data.

- The difference in charged particle pseudorapidity density between NSD p+$\bar{\text{p}}$ and p+p collisions at $\sqrt{s}$=900 GeV is about 4.5% in the PYTHIA calculations and 4.9% in PACIAE. They are larger than the range of 0.1-0.2% resulted from extrapolating the CERN ISR measurement [22] to $\sqrt{s}$ =900 GeV.

Figure 1 gives ALICE data of charged particle pseudorapidity distributions in p+p collisions at $\sqrt{s}$ =900 GeV [13] together with the results from PYTHIA and PACIAE calculations. We see in this figure that the ALICE data are better reproduced by PACIAE than PYTHIA.
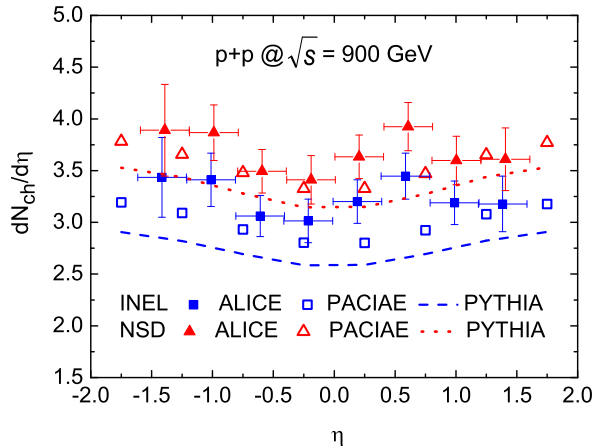
FIG. 1: (Color online) Charged particle pseudorapidity distributions in INEL and NSD p+p collisions at $\sqrt{s}$=900 GeV. The full squares and triangles are ALICE INEL and NSD data, respectively, taken from [13]. The open squares and triangles are the PACIAE results. The dashed and dotted curves are the PYTHIA results.

Both PYTHIA and PACIAE results show the similar shallow valley at $\eta \sim 0$ to the ALICE data, and the better symmetry relative to η=0.

The calculated center-of-mass energy dependence of the charged particle pseudorapidity density at mid-rapidity is compared with the ALICE data in Fig. 2. One sees in this figure that the power-law fit is better reproduced by PACIAE rather than PYTHIA both for INEL and NSD. The PYTHIA results are below the corresponding power-law fit lines for both INEL and NSD. The PACIAE NSD results deviate from the corresponding power-law fit lines at $\sqrt{s} \sim 2500$ GeV. Then this deviation increases with increasing center-of-mass energy. The role of parton rescattering also increases with increasing center-of-mass energy. For instance, the difference between PACIAE and PYTHIA NSD results (in percentage) increases from 5.1% at $\sqrt{s}$=200 GeV to 15.4% at 5500 GeV and then to 24.2% at 14000 GeV.

We compare the charged particle pseudorapidity distributions calculated by the PYTHIA and PACIAE models for NSD p+p collisions at $\sqrt{s}$=200, 900, 5500, and 14000 GeV in Fig. 3. In this figure the open and full symbols are the PYTHIA and PACIAE results, respectively. The circles, squares, triangles, and diamonds indicate the results in $\sqrt{s}$=200, 900, 5500, and 14000 GeV p+p collisions, respectively. One sees the following features in this figure:

- The charged particle pseudorapidity density at mid-rapidity and the width of center rapidity plateau increase with increasing center-of-mass energy monotonously.
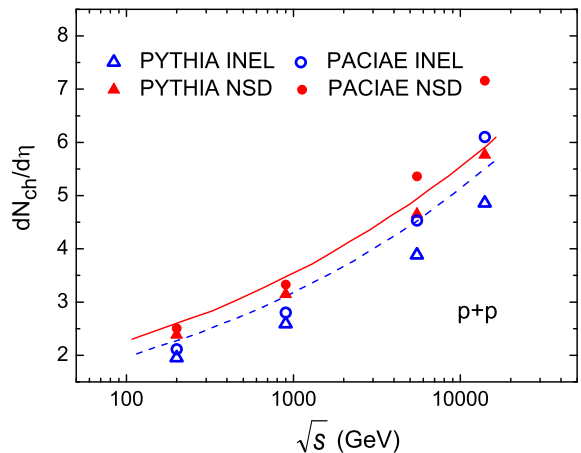

FIG. 2: (Color online) Charged particle pseudorapidity density at mid-rapidity ($|\eta| <$0.5) in p+p collisions as a function of the center-of-mass energy. The triangles and circles are the PYTHIA and PACIAE results, respectively. The full and open symbols indicate the NSD and INEL p+p collisions. The dashed and solid lines indicate the fits to experimental data ($\sqrt{s} <$ 1900 GeV) by a power-law dependence on the energy for INEL and NSD interactions, respectively [13].

- In the center pseudorapidity region the PACIAE results are larger than PYTHIA. However, one sees the opposed situations in the outer pseudorapidity region. This trend increases with increasing center-of-mass energy. That means the parton rescattering effect (the QGM formation probability) in p+p collisions increases with increasing center-of-mass energy as well.

IV. CONCLUSIONS

Using the PYTHIA model (without parton rescattering) and the parton and hadron cascade model PACIAE (with parton rescattering) we have investigated the charged particle productions in INEL and NSD p+p collisions at $\sqrt{s}$=200, 900, 5500, and 14000 GeV as well as p+$\bar{p}$ collisions at $\sqrt{s}$=900 GeV.

The calculated charged particle pseudorapidity density at mid-rapidity ($|\eta| <$0.5) and the pseudorapidity distributions in p+p and p+$\bar{p}$ collisions at $\sqrt{s}$=900 GeV well reproduce the corresponding ALICE and UA5 data [13, 18]. The calculated $dN_{ch}/d\eta$ at mid-rapidity as a function of center-of-mass energy well meets with the power-law dependence lines fitted to the experimental data in the $\sqrt{s} <$1900 GeV region [13]. Above this region the deviation of PACIAE NSD results from NSD power-law dependence line increases with increasing center-of-mass energy. The calculated charged particle pseudo-
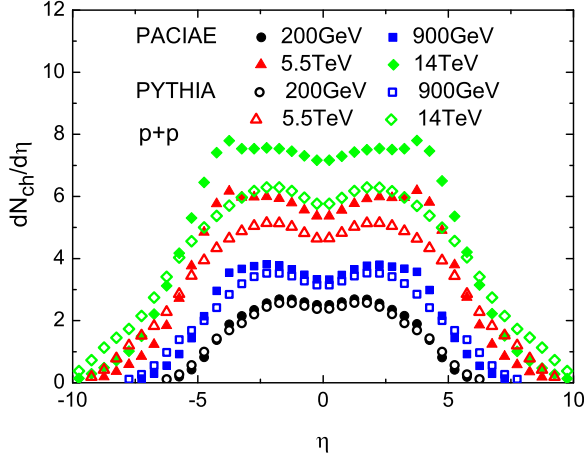
FIG. 3: (Color online) Charged particle pseudorapidity distributions in NSD p+p collisions at $\sqrt{s}$=200 (circles), 900 (squares), 5500 (triangles), and 14000 GeV (diamonds) calculated by PYTHIA (open symbols) and PACIAE (full symbols) models, respectively.

rapidity distributions, similar to the ALICE data, show a nearly plateau structure at mid-rapidity with a shallow valley at center pseudorapidity. That plateau width increases with increasing center-of-mass energy.

The parton rescattering effect plays an important role in reproducing the experimental data. The parton rescattering effect becomes larger and larger with increasing center-of-mass energy. This also means the QGM formation probability in the p+p collisions increases with increasing center-of-mass energy. Therefore the QGM is possible to be formed in the early stage of p+p collisions at ALICE or higher energy.

Acknowledgments

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